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Attitudes of Metro Drivers Towards Design of Immediate Physical Environment and System Layout

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Abstract In this study, the authors examined attitudes of the Tyne & Wear (T&W) Metro drivers towards system design-related factors and their influence on the propagation of driver-related incidents. The system design features assessed include the position of running signals, visibility of different signal types, and platform location in relation to the travelling direction. The methodology based on data gathering through a self-administered questionnaire distributed among the drivers has been used. These data have been evaluated using multivariate analysis techniques against historic data on incidents to uncover potential relationships between drivers' perceptions and incident occurrence. The results show that the participants do not tend to consider system design factors as influential towards incident propagation. However, the analysis shows correlation between the driver responses and historical incident data such as corroboration of the increased incident propagation risks during the engineering works and the possessions.

Keywords Urban railways · Metro · Human–system interface · Human factors · Safety · PSF

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1 Introduction

Despite significant progress in the automation of different processes, railways still rely heavily on the performance of front-line staff, especially drivers. Being safety critical systems, the railways are assessed on their safety-related performance, and as such, the amount of incidents and accidents has serious consequences. Most incidents can be linked to the front-line staff as they still carry approximately 80 % of the risk in the industry [1]. It is accepted that numerous performance shaping factors (PSFs), which also include human factors (HF), can affect train drivers and influence incident propagation. The operation of the railways involves a variety of PSFs, including very important system design-related factors [2]. However, there appears to be no holistic understanding of the influence of system design-related PSFs on train drivers' performance. Even though the field of PSFs and HFs has been growing significantly recently, existing research still appears to be fragmented and studying a single railway physical environment aspect at a time.

Metro systems have been even less successful in attracting human factors & ergonomics (HF&E) specialists so far. It is important to treat metro systems separately from the mainline railways as they have certain differences affecting incident propagation and consequences. Considerably smaller variability of rolling stock, routes, track layout, and infrastructure in a closed system enhances drivers' route knowledge. The high capacity nature of metro systems leads to shorter headways and distances between stations thus increasing amount of signals and station stops encountered by drivers as well as risks of incidents associated with those. However, the use of automatic train protection (ATP) along with highly efficient brakes creates a risk profile that is different from that of the mainline railways.

This paper explores the Tyne & Wear Metro (T&W Metro) drivers' perception of causal factors behind some driver-related incidents. The paper provides an overview of drivers' attitudes towards different design-related PSFs which have been identified as potential latent failures in previous research.

The questionnaire surveys are an established approach to source attitude data from train drivers. Questionnaire studies have been carried out to investigate train drivers' motivations [3], organisational factors in incident reporting [4], influences of praise the drivers receive [5], physiological reactions to accidents [6], and effects of job stress on train drivers [7]. Self-administered questionnaires were used by Yum, Roh [8] to explore symptoms of post-traumatic stress disorder among Korean train drivers. Further questionnaire study by Jeon, Kim [9] showed that post-traumatic stress, in conjunction with sleep deprivation, is a major factor in human errors among train drivers. Effects of driver's chronotype on performance and quality of life had been assessed through a series of questionnaires by De Araújo Fernandes Jr, Stetner Antonietti [10]. Design of immediate physical environment, specifically cab environment, and train drivers' attitudes towards it had been assessed by Stevenson, Coleman [11]. They had used numerous mixed methods (quantitative and qualitative questions combined) questionnaires which asked train drivers to assess ergonomics and design changes of the new Tangara train in Australia. More examples of questionnaire used for evaluation of physical design can be found in automotive industry. For instance, attitudes on car design requirements have been studied among ageing demographics of drivers [12].

Section 2 briefly introduces the Tyne & Wear Metro system; Sect. 3 describes the methodology used including the questionnaire-based data gathering; and Sect. 4 introduce the results discussing them leading to some conclusions in Sect. 5.

2 Tyne & Wear Metro System

The Tyne & Wear Metro is located in the Tyne & Wear conurbation connecting Newcastle, Sunderland, Gateshead, South and North Tyneside. It is first opened in 1980 and mostly adapted existing heavy rail infrastructure. Today, the system spans 77.5 km and has 60 stations. The fleet consists of 90 twin-section articulated Metrocars, which currently run in pairs when in service. The rolling stock is currently undergoing its ¾ life refurbishment. The system has two routes. The South Gosforth to Pelaw section of the network is considered the "core of the system" as both routes pass through it.

The majority of the stations in the T&W Metro system are located overground. There are only eight underground stations in the network. Most stations have two platforms with a length suitable for two-car train sets. Some of the underground stations, the "legacy" stations adapted from the older heavy rail system, and some other stations have longer platforms. There are twelve line and service terminus stations in the Metro. Line terminuses have either a single platform or a layout allowing trains to arrive at any of the two available platforms. The service terminuses are used for short services and have turn-back facilities at a station or in sidings. The majority of stations on the network have a standard design with a running signal and dispatch equipment at the platform's edge. An example of such a standard design is shown in Fig. 1. However, some of the adapted metro stations have retained the previous heavy rail design, e.g. Tynemouth station has a canopy roof over the station and significantly wider platforms. Despite the standardised approach, many design aspects change from station to station, e.g. the point where passengers enter to the platform, the position and presence of a running signal, and the type of dispatch equipment.

The Tyne & Wear Metro operates on its own infrastructure as well as some sections using shared track with Network Rail. Thus there is a variety of signalling used, all fixed block. Most of the system has simple two-aspect signalling with occasional fixed distants and three-aspect signals. However, the Pelaw to South Hylton route uses Network Rail infrastructure and subsequently utilises standard mainline four-aspect signalling with yellow and double yellow signals. As of May 2014, signals using LED technology were only installed on the section shared with Network Rail as well as at the depot. The Metro drivers do

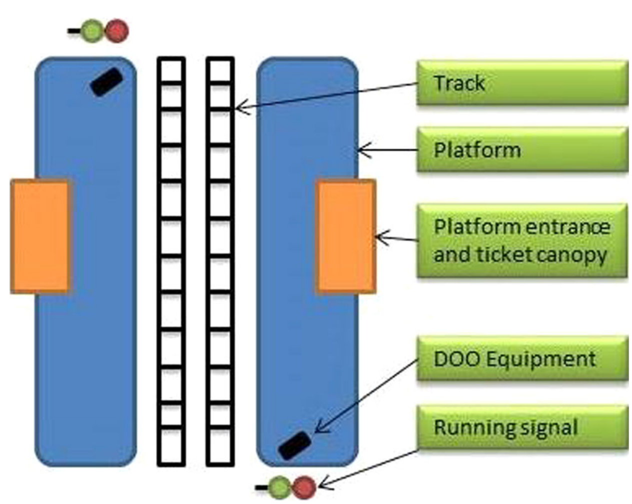

Fig. 1 An example of the standard station layout in the T&W Metro

not have the benefit of automatic warning system (AWS) or train protection and warning system (TPWS) available to the mainline train drivers on the same route. The automatic train protection (ATP) system controls overspeeding and signal passed at danger (SPaD). However, the speed control infrastructure is at certain locations only. The ATP system used is the Indusi system which is a version of German mainline railway warning and supervision system Induktives Sicherungssystem.

More information on the T&W Metro can be found in [13–15]. Fenner [16] describes the features of ATP used in the T&W Metro.

3 Methodology

The data for the study have been gathered using a custom-made questionnaire distributed among the T&W Metro drivers. Questionnaire surveys are an established practice to source attitude data. It has been extensively used in the railway industry in the past. The results were analysed against historical data to uncover relations of statistical significance. Descriptive statistics and the multivariate analysis have been used to explore underlying structures of the data collected.

3.1 Historic Incident Data

The questionnaire survey described in this paper followed up an analysis of the past incident statistics in the T&W Metro. The historic incident data included 1282 incident reports from the T&W Metro for a period between April 2011 and 2013. The focus of the past incident data analysis was on the location of driver-related incidents and potential system design-related factors affecting incident propagation. The driver-related incidents include signal passed at danger (SPaD), overspeeding, station overrun, failure to call, passenger entrapments, wrong-side door activation, and wrong-route incidents. Findings from the past incident data were used to create the questionnaire in order to source further data and reinforce some results. In summary, the incident data analysis revealed that in the T&W Metro, which is highly standardised in terms of the design of the physical environment (signals, stations and station infrastructure, track layout), an elevated rate of driver-related incidents occurs at locations deviating from a standard design. Some of the results are included in the discussion to provide more insightful analysis of the drivers' responses and whether their perceptions are similar to what incident statistics suggests.

3.2 Data Gathering

In the beginning of the questionnaire, the respondents were asked to assess a list of statements about their perception of different aspects of the system. They had to select an appropriate answer from a 7-point Likert scale (from strongly agree to strongly disagree). The scale used in the study is shown in Table 1. Due to the ordinal nature of the Likert scale, the descriptive statistics selected for the statements are mode and median. The statements along with the descriptive statistics are shown in Table 2.

Secondly, additional questions were asked in order to understand the perceived risks regarding passenger entrapment and wrong-side door incidents. The metro drivers had to mark the list of pre-selected PSFs based on their importance as a potential cause for each incident type. The marking scale was 1–10, with 1 being not important and 10 being very important. Due to the interval nature of the marks, the descriptive statistics selected for these questions were the mean and standard deviation. The mean marks for PSFs associated with wrong-side door incidents and passenger entrapment are shown in Tables 3 and 4, respectively. The respondents also had an opportunity to add other factors that they feel to be important.

Finally, this particular metro system allows for a direct comparison between different signal types as the drivers have to operate on both mainline and metro-only infrastructure. Hence, the drivers were asked to give a mark to some of the most frequent signal types in the system. Table 5 contains descriptive statistics for this comparison. Similar to the previous questions, there was a non-compulsory follow-up open question for the respondents to explain their choice of marks.

The drivers also were asked to tick the driver-related incidents they have been involved in the past 3 years. This information was later used to analyse whether previous involvement in certain incidents changes drivers' perception of effects arising from the physical environment. The Mann–Whitney U test has been used to compare the samples. It is important to note that samples for all the incident types, apart from wrong-side door activations, were significantly different in size. However, the U test does not require equal sample sizes [17].

The questionnaire study has been self-administered, but participants had means of contacting the authors if they had any issues. In total, 26 metro drivers participated in this study (17.3 % of all the T&W Metro drivers). Out of the 26 respondents, 23 were males and 1 female. Two respondents did not state their gender. 42.3 % of the participants have been metro drivers less than 3 years. The overwhelming majority of the respondents were aged between 26 and 35.

Table 1 The 7-point Likert scale used in the study

Strongly agree	Agree	Just agree	Not sure	Just disagree	Disagree	Strongly disagree

Table 2 The drivers were asked to assess statements on 7-point Likert scale

Statement	Mode	Median
My route knowledge of the Metro is good	Strongly agree	Strongly agree
My confidence reduces while driving during possessions or engineering works	Just agree	Just agree
The training provided for operations in degraded mode is adequate	Just agree	Just agree
The moment I enter or leave a tunnel, I feel more alert	Just disagree	Disagree
Running signals between the stations are easy to interact with	Agree	Agree
Running signals at the stations are easy to interact with	Agree	Agree
I am less alert if the outside physical environment is monotonous	Not sure	Just disagree
I prefer varied outside environment, such as a mix of vegetation and buildings	Just agree	Agree/ just agree
The recent change in door closing procedure from 2 to 1 button sequence is easier to operate	Just agree	Just agree
A 1-button sequence might increase the occurrence of passenger entrapment	Agree	Strongly agree
I like mirrors as station dispatch equipment	Just agree	Just agree
I like monitors as station dispatch equipment	Just agree	Just agree
When coming to a scheduled stop I pay attention to a running signal at the platform end	Agree	Strongly agree
Running signals located far from the platform end can make selection of a stopping position difficult	Disagree	Disagree
It is difficult to choose which side doors to open when station signals and the platform are on opposite sides	Just disagree	Disagree
Signalling at ground level can be confusing after driving a train in passenger service	Just disagree	Just disagree
The change of platform side does not affect my ability to select correct side to open the doors	Just agree	Agree/just agree
The stations differ a lot in terms of driver visibility of passengers on a platform	Strongly agree	Strongly agree
If the time between two stations is more than 2.5 min, this improves my alertness	Not sure	Not sure
I feel more alert when the time between stations is less than 1 min	Not sure	Not sure
I prefer steep change in speed limits rather than gradual change	Not sure	Not sure
My familiarity with operational protocols at sidings is very good	Agree	Agree
I have good familiarity with the layout of the depot	Agree	Agree
I find it harder to keep within higher speed limit than lower speed limit	Just disagree/ disagree	Disagree

Table 3 The drivers were asked to mark causal factors for wrong-side door incidents in terms of importance

Potential causal factor	Mark/10	SD
Attention lapse	8.19	2.433
Lack of reminders for drivers at stations	3.73	2.523
Layout of the door control	6.35	3.019
Distractions	7.88	2.142
Inadequate training	2.96	2.891

4 Discussion

4.1 Metro Drivers' Safety Performance During Engineering Works

Route knowledge is one of the most important skills of a train driver as a considerable part of their movement authority is often hidden from a driver's view [18]. Taking into account the more closed nature of metro systems in comparison to mainline railways, it is safe to assume that

Table 4 The drivers were asked to mark causal factors for passenger entrapment incidents in terms of importance

Potential causal factor	Mark/10	SD
Night time	5.85	3.283
Snow	2.96	2.375
Rain	4.27	2.647
Mist	5.96	2.793
Direct sunlight	8.04	2.490
Vegetation overgrowth	3.77	2.971
Location of station infrastructure, e.g. CCTV cameras	7.69	2.462
Overcrowding at a platform or in a train	8.73	1.733
Winter clothing on passengers	4.12	2.889
Shopping bags and suitcases	5.88	2.718
Layout of the stations	6.35	2.652
Design of passenger approaches	7.19	2.871
Mobility aid equipment, e.g. walking sticks, crutches	6.73	2.677
Station dispatch instructions/procedures used in the Metro	4.92	2.560
Low height passengers, e.g. children	5.42	2.656

Table 5 The drivers were asked to assess how easy to interact and interpret different signal types

Signal type	Mark/10	SD
Running signal on Network Rail infrastructure	9.42	1.332
Running signal on Tyne & Wear Metro infrastructure	8.54	1.529
Repeater	8.77	1.583
Advance warning signal	8.35	1.696
Flashing aspects	9.04	1.685
Ground position lights	7.62	2.041
Junction indicators	8.46	1.772

the route knowledge of the metro drivers is at a very high level. This is also supported by a relatively small amount of category A SPaDs in T&W Metro with a considerably higher frequency of the running signals than in the main-line railways. The drivers also believe that they know the system very well. Moreover, involvement in category A SPaD incidents does not make the drivers reconsider their route knowledge ($U = 21.5$, $p = 0.234$). On the other hand, the incident data analysis suggests that the increased familiarity with the day-to-day running causes a decrease in drivers' safety-related performance during non-routine operations. For example, engineering works and possessions affect the routine operation protocols in the system. The drivers' assessment corroborates a reduction in confidence in such operational conditions.

4.2 Operations at the Depot and Sidings

Even though driving into sidings/the depot is a frequent task for drivers working shifts around rush hours, it does not account for a significant percentage of their shift. Hence, when the large percentage of all category A SPaDs and the low percentage of the shift spent in these locations are considered, this suggests that there are issues in the design of the locations and operational procedures. The signalling is the main difference at the depot and the sidings compared to the rest of the network with the majority of the signals being ground position lights. Even though the majority of the drivers disagree with added complexity of those locations and ground position lights, they gave this type of signals the lowest mark. Moreover, participants' involvement in category A SPaDs does not influence the attitudes of the drivers towards the ground position lights ($U = 28$, $p = 0.663$). The respondents mention that the ground position lights are hard to see at times due to low brightness and a poor choice of location. It is possible that the drivers do not see any hazard in this type of signalling in the context of day-to-day driving. However, when compared with different types of signals, they perceive the ground position lights as the hardest to interact with. It is also possible that the ground position lights are the hardest to interact with in the beginning of a shift before driving in passenger service.

4.3 Running Signals

Further investigation into the category A SPaD accidents in the T&W Metro showed a large proportion of these being start against a signal SPaD (SASSPaD) accidents. SASSPaD occurs when a train leaves a station against a red signal at the station's running signal. However, the drivers did not see the difference between running signals at and between the stations. Taking into account a very low number of SPaDs compared to the overall amount of signals encountered by the metro drivers in an operational year, it is possible that many drivers even do not notice any difference. However, the drivers previously involved in category A SPaDs are more inclined to evaluate both running signals at the stations ($U = 9.5$, $p = 0.032$) and between the stations ($U = 11.5, p = 0.051$) less positively. Moreover, the SASSPaDs are potentially caused by non-signalling-related factors as stations have more dynamic environment than tracks between those.

Analysis of the historic category A SPaD statistics also revealed that only 4 % of such incidents happen between Pelaw and South Hylton (mainline railway owned by Network Rail). This part of the network accounts for almost 25 % of the length of the system and 21 % of the signals in the system. This line differs from the rest of the network in several aspects. Those include bigger distances between stations and straighter alignment of the track. However, the biggest difference is use of mainline 4-aspect signals. These mainline signals use LED lights, whereas conventional light bulbs are used in the rest of the network. Exploring mean marks for the running signals, it is possible to claim that drivers prefer the running signals on Network Rail infrastructure. The drivers also expressed concerns that the signalling on the metro infrastructure does not give as much advance warning and is more prone to overgrowth. The incident data analysis returned no correlation between approach distance and any incident type propagation. The drivers also have not reported any effect on their alertness due to the distances between stations.

4.4 Effects of the Physical Environment on the Drivers' Performance

The results show that the drivers disagree slightly with negative effects of the monotonous physical environment but prefer a varied landscape around a train. Research from the automotive industry indicates that a long exposure to the monotonous physical environments negatively affects arousal levels of car drivers [19]. The metro drivers are exposed to such a physical environment frequently, for example, when driving through tunnels and walls of vegetation. In fact, locations associated with prolonged driving in a tunnel were among the worst performing in terms of driver-related incidents. It is possible that the respondents struggled to assess their alertness level in retrospect, considering that it decreases with time [20]. However, a change of physical environment is known to boost drivers' arousal levels for a limited period of time [21]. Hence, alertness and safety-related performance were expected to rise in locations associated with the most extreme change of the physical environment in the system—tunnel exit or entrance. Conversely, the metro drivers disagree that their alertness rises at such moments. Furthermore, statistics from the historic incident data analysis support this statement. The locations associated with tunnel exits/entrances in the T&W Metro displayed an increase in incident levels.

One way in which a decrease in alertness manifests itself is via an increased rate of drivers' lapses. However, drivers' perception of importance of the attention lapse causal factor (Table 3) has no influence on their views on the effects of the physical environment on their state of alertness. None of the five related statement displayed any statistical significance in a Kruskall–Wallis H test with low (1–3), medium (4–7), and high (8–10) marks for the attention lapse factor as a categorical variable.

4.5 Station Overruns

Even though station overruns are usually associated with low rail adhesion (LRA), there were several incidents in the studied period which were outside the LRA season. An in-depth investigation of the locations revealed unusual positions of a running signal. Instead of being at a platform's end, the running signal at such locations was located further down the line. The respondents indicated that while attention is paid to the running signal at the platform while coming to a scheduled stop, their perception is that the two (the running signal and the stopping position) are not related. The station overruns have been historically treated as LRA-related incidents in T&W Metro which could have led to the participant not being able to consider other factors. However, the statements were worded in a way that does not make the association with a certain driver-related incident type obvious. Most respondents have never been in a station overrun incident outside the LRA season. On the other hand, the most important factor in choosing the stopping point for a driver is the ability to interact with driver only operations (DOO) dispatch equipment.

4.6 Passenger Entrapment Incidents

The T&W Metro uses both monitors and mirrors as DOO equipment. The responses indicate that these are equally liked and no preference has been highlighted. However, poor-quality monitors and inappropriate positioning of cameras have been mentioned as a causal factor often, but not as often as passengers' behaviour. Many passenger entrapment incidents in the T&W Metro are door misuse by passengers. Three of the four worst-performing stations, in terms of passenger entrapment, in the T&W Metro were the stations with very high patronage levels and monitors as the dispatch equipment. However, all of these stations have issues with the design of passenger approaches. The approaches to a platform at these stations are located outside of driver's view. Along with poor positioning of the cameras, it causes situations when the passengers, who run for a train, emerge suddenly into a driver's field of view. The respondents strongly agree that there is a significant discrepancy in terms of visibility of the passenger approaches throughout the system. Hence, the PSFs associated with cameras and the station design received very high marks as shown in Table 4.

Analysis of the time when passenger entrapment incidents happen in the Metro revealed a midday peak (12–3 pm). From this information and the description of the incidents, it was assumed that a higher percentage of elderly passengers creates additional entrapment risks. The drivers tend to agree with this giving the related causal factor fifth highest average mark. The high mark for direct sunlight does not align with the midday peak statistics as the sun is in zenith during that time. Hence, there is little risk of direct sunlight affecting the DOO equipment. However, morning and evening rush hours also have significantly elevated levels of passenger entrapments. This is when the sunlight causal factor can be the most important.

T&W Metro has recently changed the door closing procedure from two-button to one-button operation. In the past, the drivers had one more button to press after a door closing tone has sounded. This means that they were able to react if a passenger tried to misuse the doors by running for a train after the warning tone. The respondents admit that the new procedure left them with less control over a situation and increased the risk of passenger entrapment. This could be the reason behind a doubling of the number of passenger entrapment incidents between the two operational years studied.

4.7 Speed Control

The historic incident data analysis has revealed that the most problematic locations, in terms of overspeeding incidents, are predominantly stations with a lower than usual speed limit. The metro drivers agree that it is harder to keep to low speed limits than to the higher speed limits. It is not a case of perception of 10 km per hour (km/h) speed as very slow after driving at 80 km/h moments ago. The ATP system utilised by T&W Metro has a tolerance level of ± 2 km/h. The operator encourages the drivers to travel 5 km/h under the speed limit in locations with speed measurement magnets. Hence, at the 10 km/h locations, the drivers have to stay 50 % under the speed limit, whereas at the 80 km/h, the same decrease in speed accounts for less than 10 %. Moreover, when the problematic locations were compared, the worst incident rates were demonstrated by a station with the fastest drop in speed limits. However, the drivers could not answer what rate of change of speed limits they prefer. It is possible that the statement was worded incorrectly with adjectives "steep" and "gradual" to define rates of changes.

4.8 Wrong-Side Door Activations

Similar to the overall driver-related incident statistics, wrong-side door activations have been localised to the stations with designs deviating from the standardised design. It could be an unusual position of a signal, Victorian built environment at the legacy stations or other deviation. Furthermore, stations with a different platform side, compared to a previous station, demonstrated increased levels of such incidents. The drivers disagree that either change of the platform side or an unusual positioning of a signal affects their door-opening duties. They scored the attention lapse and distraction high as the most important potential causes for this type of incident. Difference in the layout of the door control in different cars has been marked high too. However, when the respondents were asked what stations they believe to carry the highest risk and why, they mostly mentioned stations associated with the platform side change for the same reason.

Throughout the questionnaire, the respondents assessed their own performance very high stating that they do not get affected by different design-related factors. It is known that the respondents tend to be mildly positive with Likert-type questions [22]. Perhaps the drivers struggled to project the statements on themselves or were not fully convinced that the survey is fully anonymous. Moreover, lack of experience in being involved in particular incident type, and subsequent lack of retrospective analysis of an incident, affected drivers' answers. Mann–Whitney U test ($U = 35.5$, $p = 0.017$) shows that the drivers previously involved in the wrong-side door incidents tend to agree more that it is harder to choose the correct side doors to open when the platform side changes.

5 Conclusions

The data gathered in the survey provide a valuable insight into how drivers perceive design-related risks in the system. It is possible to claim that, in general, drivers do not perceive design-related factors to be those which notably affect them. They predominantly rated their performance to be independent from the effects of various features of the station design, track layout, and the signalling. However, when asked to compare various PSFs outside of a situational context, they are able to discriminate between those. Thus the respondents assign various risk levels to different

PSFs related to the same incident type. It is possible that the drivers struggle to associate themselves with the situations described in the statements.

Findings from the historic incident data analysis have been supported by the drivers' responses. Those include the effects of distance and change of physical environment on alertness levels, problems with ground position light signals and the passenger approaches at the stations, increased risks during engineering works and possessions. Moreover, the drivers agree on the increased risk of passenger entrapment due to new procedures, potential effects from the change of platform side, and the increased difficulty of keeping to a low speed limit.

The drivers, similar to the incident data analysis, do not agree on negative effects of long distances between the stations or positive effects from entering/exiting a tunnel. The drivers disagree that a monotonous outside physical environment affects their safety-related performance negatively but still prefer a varied physical environment.

The participants previously involved in some of the driver-related incidents seem to perceive the physical environment features associated with the incident type less positively. They are able to assess a situation presented based on their experience. Most likely they had to analyse an incident in retrospective as a part of the compulsory debrief by a safety manager.

6 Further Research

Differences have been found between effect magnitude suggested by the historic data and driver attitudes for some of the features of system design. Namely, additional attention needs to be focused on complexity of the sidings and the depot, factors involved in SASSPaD incidents, and effects of a running signal on a stopping position. Further steps are required to investigate whether the drivers do not perceive the physical environment as something that introduces performance shaping factors or the hypotheses drawn from past the incident data analysis are incorrect. Non-intrusive psychometric methods like eye-tracking or posture sensors can be useful for this type of investigation.

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